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(Research Article)

Development of RBL-STEM Learning to Improve Students' Conjecturing Thinking Skills in Asymmetric Cryptography Problems in Blockchain Technology Using Super (a, d)-Hyperedge Antimagic Total Labeling of Hypergraphs

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Abstract

The rapid evolution of blockchain technology underscores the need to enhance students' conjecturing thinking skills. Research-Based Learning (RBL), combined with Science, Technology, Engineering, and Mathematics (STEM) approaches, offers an effective framework for this purpose. This study aims to explore RBL-STEM activities, describe the process of developing RBL-STEM learning materials, and analyze the effectiveness of these resources in improving students' conjecturing thinking abilities. Using a research and development (R&D) methodology, the study produced various learning tools, including assignment designs, worksheets, and learning outcome assessments. The developed materials demonstrated a validity score of 96.80%. A trial conducted with 37 students revealed that the RBL-STEM resources were highly effective (92.12%) and practical (97.71%), with students showing strong engagement and positive feedback. The study found significant improvements in students' conjecturing thinking skills as they tackled super (a, d)-hyperedge antimagic total labeling problems in the context of asymmetric cryptography for blockchain technology. Students' proficiency levels were categorized into three groups: high, medium, and low. Statistical analysis, phase imaging, N-Vivo software, and word cloud tools validated the results, further confirming the enhancement of conjecturing thinking skills. This research highlights the potential of RBL-STEM to develop critical thinking abilities in practical applications, such as solving complex blockchain-related problems.

Keywords: Conjecturing; Research Based Learning; STEM; Super $(\boldsymbol{a}, \boldsymbol{d})$-Hyperedge Antimagic Total Labeling of Hypergraphs; Asymmetric Cryptography; Blockchain

1. Introduction

The rapid advancements in blockchain technology have revolutionized various industries by ensuring secure and decentralized data transactions. Blockchain relies heavily on asymmetric cryptography to safeguard its processes, making it essential for future generations to develop the critical thinking and problem-solving skills required to address challenges in this domain [1][2]. Among these skills, conjecturing thinking defined as the ability to formulate, test, and refine hypotheses plays a pivotal role in addressing complex mathematical and computational problems [3].

To enhance conjecturing thinking skills, innovative pedagogical approaches such as Research-Based Learning (RBL) integrated with Science, Technology, Engineering, and Mathematics (STEM) education are gaining attention. The RBL-STEM framework emphasizes inquiry-based learning where students actively engage in problem-solving and critical

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analysis, fostering deeper understanding and skill development [4]. Within this framework, mathematical tools like super (a, d)-hyperedge antimagic total labeling of hypergraphs provide a rich context for exploring asymmetric cryptography problems in blockchain applications [5].

A hypergraph is a generalization of a graph where edges, called hyperedges, can connect more than two vertices. Hypergraphs have been widely studied for their applications in network theory, combinatorics, and computer science [6][7]. In the field of cryptography, hypergraphs play a crucial role in representing relationships and structures in data systems, including blockchain technology. The concept of super *(a,d)*-hyperedge antimagic total labeling extends traditional graph labeling by assigning distinct integers to both vertices and hyperedges of a hypergraph such that the sums of labels for hyperedges form an arithmetic progression with the first term a and common difference d [8][9]. This type of labeling has been studied for its mathematical elegance and its potential applications in cryptographic systems, where such configurations provide additional layers of security and complexity [10].

Despite its importance, conjecturing thinking remains underdeveloped in many educational settings due to the lack of targeted and context-driven learning resources. Existing studies have shown the potential of RBL-STEM approaches to bridge this gap by creating meaningful learning experiences that connect theoretical concepts to real-world applications [11][12]. However, there is limited research on how such approaches can be applied to asymmetric cryptography and blockchain technology using advanced mathematical constructs.

This study aims to address this gap by developing and validating RBL-STEM learning materials designed to improve students' conjecturing thinking skills. The learning materials focus on solving super (a, d)-hyperedge antimagic total labeling problems of hypergraphs, a mathematical framework with direct applications in cryptographic systems. This research contributes to the broader discourse on STEM education by providing insights into the integration of advanced mathematics and emerging technologies into educational practices. The findings aim to support educators in designing innovative curricula that prepare students for the challenges of the digital age

Based on the RBL-STEM syntax that has been carried out by other researchers in solving a mathematical problem, a similar study was conducted in developing an RBL-STEM learning device by solving watermarking image problems using Super (a, d)-Hyperedge Antimagic Total Labeling of Hypergraphs with the aim of improving student conjecturing skills. Based on the description above, the title taken is "Development of RBL-STEM Learning to Improve Students' Conjecturing Thinking Skills in Asymmetric Cryptography Problems in Blockhain Technology Using Super (a, d)-Hyperedge Antimagic Total Labeling of Hypergraphs".

2. Material and methods

2.1. Research-Based Learning (RBL)

Research-based learning or RBL, is a learner-centered education that provides opportunities for learners to learn by doing so that learning becomes more significant. The aim of RBL is to increase the capacity of students and lecturers to assimilate and apply knowledge by designing a learning process that culminates in analysis, synthesis and evaluation activities. The learning process becomes more important when RBL is implemented as research findings are presented in a more contextualized way. As learning is packed with useful research ideals and research ethics by making research visible, students' capacity as future researchers becomes stronger [13]. There are three stages in RBL: exposure stage, experience stage, and capstone stage. Students gather information in the first stage, known as the exposure stage, from relevant literature and the research to be conducted. In the second step, known as the experience stage, students use their experiences and readings to discover and develop challenges. The capstone stage is the last stage, where students conduct experiments to produce answers based on concepts or objectives [14]. RBL can improve students' skills and engagement in the learning process when combined with learning instruments [15].

2.2. Science, Technology, Engineering, Mathematics (STEM)

STEM stands for Science, Technology, Engineering and Mathematics. It is an interdisciplinary approach to education. Since all four elements are needed to solve problems simultaneously, an approach based on all four elements can result in an integrated and dynamic learning system. Students use a combination of skills and talents when mastering STEM subjects. The connection between the many components of STEM is necessary so that all components in education can be used simultaneously. When students are able to integrate the four multidisciplinary components of STEM, it is a sign that they have analytical skills [16]. In STEM education: (i) Have the ability to recognize problems, explain natural phenomena, design, and draw conclusions based on evidence regarding STEM-related issues; (ii) Have specific characteristics of STEM as a form of human-initiated knowledge, inquiry, and design; (iii) Recognize how STEM disciplines shape material, intellectual, and cultural aspects; (iv) Have a desire to engage in studies related to STEM issues using the concepts of science, technology, engineering, and mathematics [17].

2.3. Conjecturing

Conjecturing skills are a type of cognitive ability where assumptions are made during problem solving to draw conclusions and make decisions [18]. Mathematical speculation skills are very important to master so that students have the ability and use them in everyday life to improve learning outcomes. The capacity to draw valid conclusions from observations, research, experiments, and investigations is known as mathematical conjecture [19].

2.4. Methods

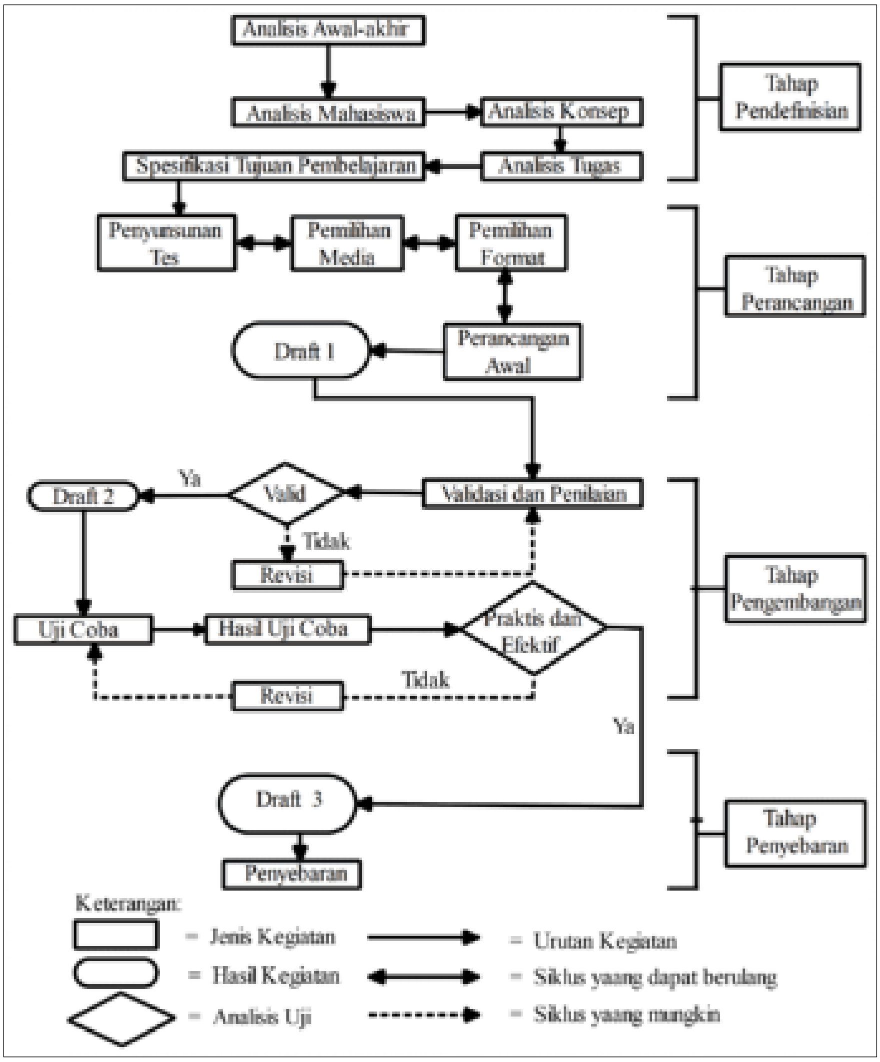
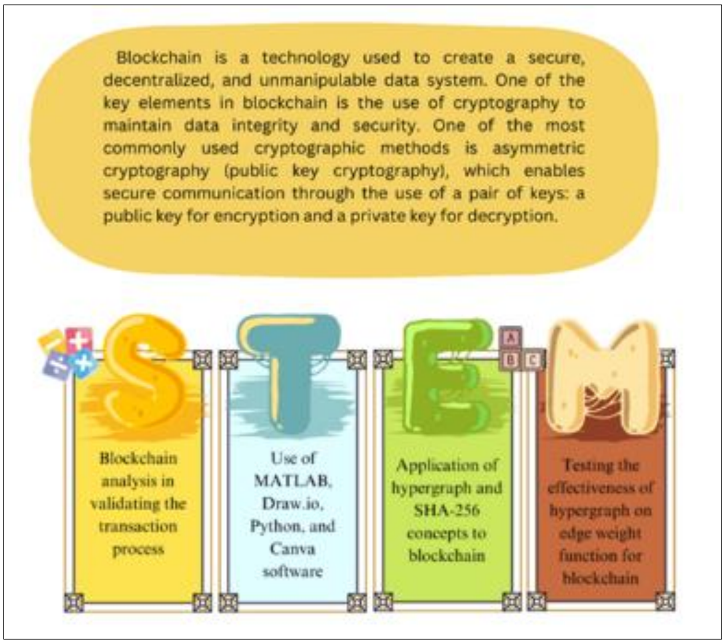


Figure 1 Stages of Learning Device Development 4-D Model

The research procedure in this study followed Thiagarajan's 4D development model, which comprises four phases: define, design, develop, and disseminate. A schematic representation of this 4D model for learning device development is presented in Figure 1. Data collection techniques utilized in the study were based on research instruments, including the validation of learning tools, observation of learning implementation, collection of learning outcomes, activity observations, and response questionnaires. Quantitative data analysis was conducted using the SPSS application to perform statistical tests, specifically the paired sample t-test.

3. Results and discussion

The RBL-STEM model encourages students to actively engage in learning through research activities. In the initial stages of the research-based learning syntax, problems are identified by research groups, focusing on open-ended issues. One such problem addressed by the researchers involves image watermarking, as illustrated in Figure 2.



Blockchain is a technology used to create a secure, decentralized, and unmanipulable data system. One of the key elements in blockchain is the use of cryptography to maintain data integrity and security. One of the most commonly used cryptographic methods is asymmetric cryptography (public key cryptography), which enables secure communication through the use of a pair of keys: a public key for encryption and a private key for decryption.

Figure 2 STEM elements of asymmetric cryptography in blockchain technology scheme

This research aims to solve the problem of asymmetric cryptography in blockchain technology using super (a, d)-hyperedge antimagic total labeling of hypergraph. Therefore, the RBL-STEM model has the following activity framework, 1) the first stage that students must do is to understand previous research related to the fundamentals of problems related to hypergraphs in asymmetric cryptography, 2) collect information related to asymmetric cryptography and the use of software, 3) obtain innovative applications of asymmetric cryptography based on hypergraphs, 4) analyze data and make theorems according to patterns in hypergraphs, 5) prove the accuracy of the theorems found, 6) end by explaining or representing the results and conclusions of a series of activities.

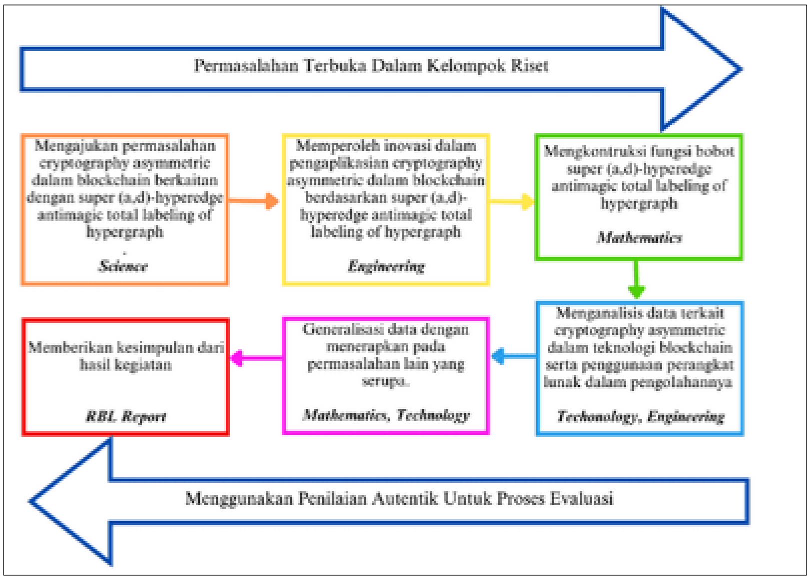


Figure 3 RBL-STEM Activity Framework for the Super $(\boldsymbol{a}, \boldsymbol{d})$-Hyperedge Antimagic Total Labeling of Hypergraphs Problem

The first stage of the 4D model is the defining phase, aimed at identifying and determining learning needs by analyzing the objectives and constraints of the material to be delivered. This phase is divided into four steps: beginning-end analysis, learner analysis, concept analysis, and task analysis. The beginning-end analysis identifies challenges students face in learning, particularly in understanding the concept of Super (a,d)-Hyperedge Antimagic Total Labeling of Hypergraphs, serving as a foundation for developing learning tools. Learner analysis gathers data on the characteristics of Mathematics Education undergraduate students at the University of Jember. Concept analysis involves identifying, detailing, and systematically organizing the concepts students need to understand about Super (a,d)-Hyperedge Antimagic Total Labeling of Hypergraphs. Task analysis focuses on identifying the core skills required for learning, aligned with the curriculum, particularly in recognizing student conjecturing based on the desired final competencies.

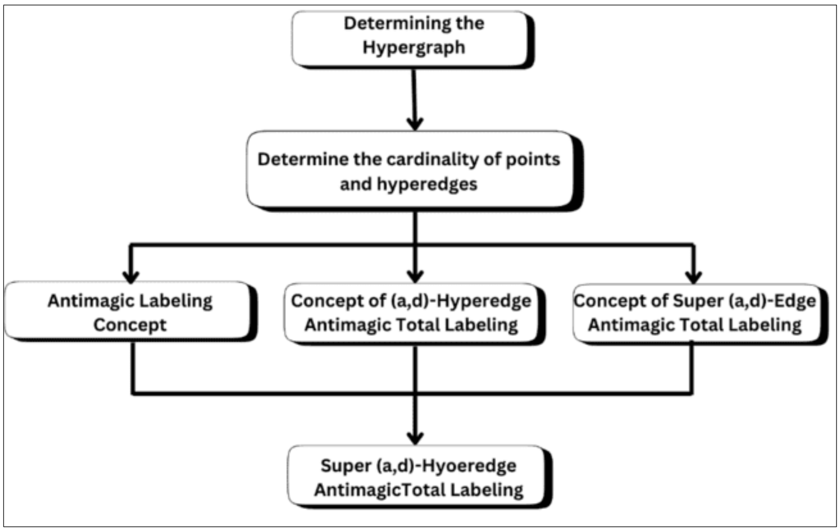


Figure 4 Super (a,d)-Hyperedge Antimagic Total Labeling of Hypergraphs Theme Concept Map

The second stage, design, focuses on developing learning tools to produce an initial draft. During this phase, the RBL-STEM device is designed to evaluate its impact on enhancing students' conjecturing abilities concerning the concept of Super (a,d)-Hyperedge Antimagic Total Labeling of Hypergraphs. This phase involves four main steps: test preparation, media selection, format selection, and initial planning. The test preparation consists of descriptive questions integrating STEM principles and related to the concepts of Super (a,d)-Hyperedge Antimagic Total Labeling of Hypergraphs and Asymmetric Cryptography Problems in Blockchain Technology. Media selection includes using tools like PowerPoint to deliver material on Super (a,d)-Hyperedge Antimagic Total Labeling of Hypergraphs, aiding students' understanding, and RBL-STEM worksheets (LKM) containing conjecturing indicators. The format selection adopts a research-based learning model combined with a STEM approach, with its learning stages serving as the instructional framework. The initial design encompasses the comprehensive creation of learning tools required prior to the study. These tools include the Semester Learning Plan (RPS), Student Task Design (RTM), Student Worksheets (LKM), and Learning Outcome Tests (THB). A visual depiction of the learning tools is provided in Figure 5.


KUNCI LEMBAR KERJA MAHASISWA
(LKM)

TES HASIL BELAJAR
(THB)

Figure 5 Initial Design of RPS, RTM, MFI, THB

The third stage, the development phase, comprises four steps: validity testing, device testing, practicality testing, and effectiveness testing. Each learning device produced during this stage undergoes validation by experts, followed by revisions based on their recommendations. Once deemed valid, the devices are trialed in the Graph Application Course for Class E of the Mathematics Education Study Program at the University of Jember. The outcomes of this stage are as follows: Revisions and improvements were made to the developed learning tools based on evaluations and suggestions from two validators. The validators determined that the devices were suitable for use with minor adjustments. According to the recapitulated validation results for RBL-STEM devices and instruments in Table 1, the average validation score was 3.89, corresponding to a validity percentage of 96.[illegible]%. Based on the validity criteria, the developed learning devices satisfy the required standard, as the score of 3.89 falls within the range $3.89 \leq Va < 4$.

Table 1 Recap of RBL-STEM Device Validation

Validation Result	Average Score	Percentage
Draft Student Assignment (RTM)	3.86	96.50%
Student Worksheet (LKM)	3.86	96.50%
Learning Outcome Test (THB)	3.84	96.16%
Student Activity Observation Sheet	3.9	97.5%
RBL-STEM Implementation Sheet	3.94	95.58%
Student Response Questionnaire	3.94	98.58%
Overall average score	3.89	96.80%

The revised and validated devices were tested with students in a class of 37 participants. The trial was supervised by eight observers, who were Master's students from the Mathematics Education program at FKIP, University of Jember. Evaluations, including observer ratings and student work, were used to assess the practicality and effectiveness of the device. The practicality test of the learning devices involved two indicators: analyzing the implementation of learning in the classroom and reviewing student response questionnaires. The classroom learning implementation analysis was based on the RBL-STEM observation sheet, evaluated by the eight observers. The average score from all observation results was 3.91, corresponding to 97.71%. According to the practicality criteria, the learning device meets the very high practicality standard, as it falls within the $90\% \leq SR \leq 100\%$ range. Based on students' responses in the questionnaire, the summary of response scores is shown in Table 2. Overall, the average positive response percentage was 93%. Given the analysis of these two practicality indicators, the device is considered practical for use.

Table 2 Summary of Data from Student Response Questionnaire Results

Assessed Aspects	Percentage
Enjoyment of the learning component	97%
Students' conjecturing skills feel trained	87%
Learning components are new	89%
Students clearly understand the language used	92%
Students understand the meaning of each problem presented	93%
Students are attracted by the appearance	91%
Students are interested in learning	95%
Students enjoy discussing with group members	100%
Overall average score	93%

The effectiveness of the learning devices was assessed using two indicators: analysis of student learning outcomes and observations of student activities. Student learning outcomes were measured through a post-test conducted on Thursday, December 5, 2024, with 37 students participating. The results showed that 32 students (86%) achieved scores above the minimum competency level, indicating classical completeness. Observations focused on initial activities, core activities, and conclusions. Student activities were analyzed using observation sheets, which were evaluated by eight observers. According to Table 3, the overall average score for student activity observations was 3.68, corresponding to a percentage of 92.12%. Furthermore, most observer feedback was positive, resulting in no significant modifications to the learning devices. Based on effectiveness criteria, the learning devices were deemed highly effective, as they achieved a score within the range of 90% $\leq P \leq$ 100%.

Table 3 Recapitulation of Student Activity Observation Results

Assessed Aspects	Average Score	Percentage
Introduction	4	100%
core activities	3.68	92.01%
Closing	3.37	84.37%
Overall average score	3.68	92..12%

The final phase is the dissemination stage, where the developed learning tools are applied on a larger scale, such as in untested classes or similar study programs. This stage aims to assess whether the tools effectively support learning activities. Additionally, quantitative data analysis is used to evaluate the improvement in students' information literacy skills. Figure 5 illustrates the distribution of students' pretest and posttest scores, while Figure 6 shows the percentages of students' conjecturing levels.

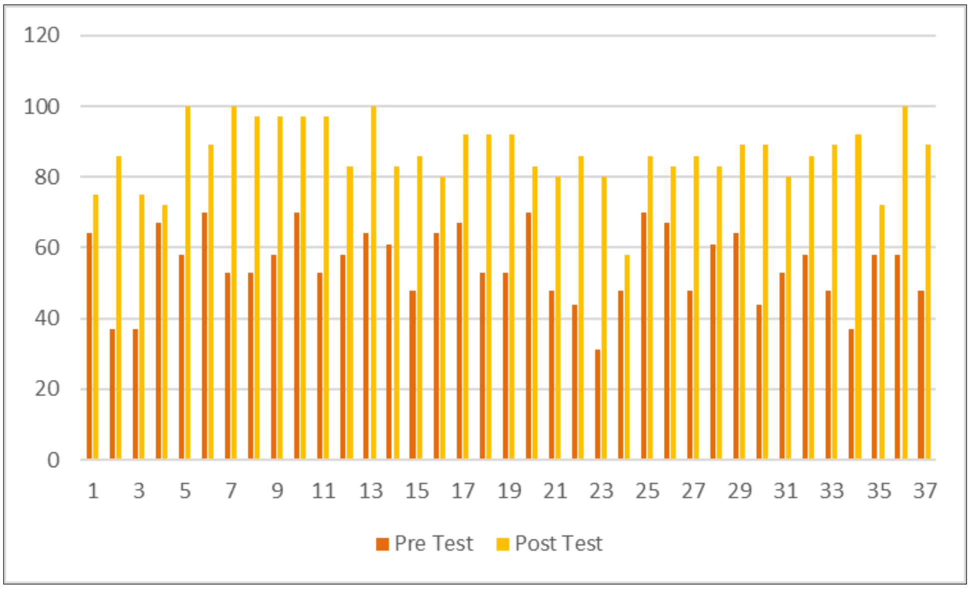


Figure 6 Graph of Distribution of Pretest and Posttest Scores

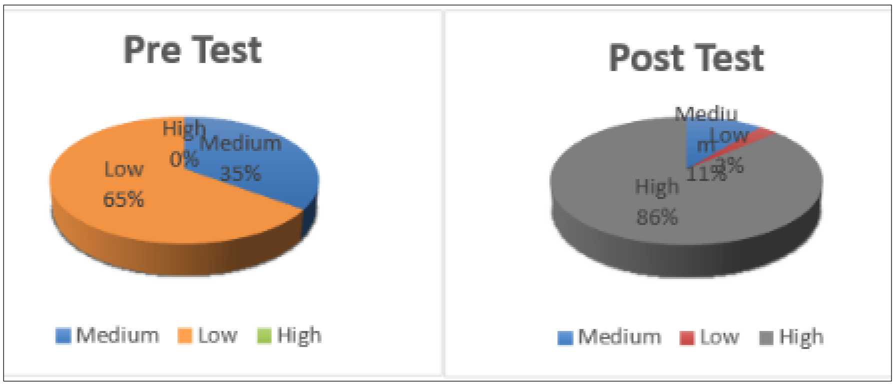


Figure 7 Percentage of Students' Conjecturing Level

In the pretest results, no students were categorized as having high conjecturing levels, 35% were categorized as having moderate levels, and 65% were classified as having low levels. In the posttest results, 86% of students achieved high conjecturing levels, the percentage of students with moderate levels dropped to 11%, and those with low levels decreased to 3%. Furthermore, a normality test was conducted as a prerequisite for the paired samples t-test, which was performed using SPSS software.

Table 4 Normality Test Results

Tests of Normality						
	Kolmogorov-Smirnov^a			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Pretest	0.119	37	0.200*	0.950	37	0.097
Posttest	0.105	37	0.200*	0.943	37	0.057

The results of the data normality test, presented in Table 4, indicate that the pretest and posttest scores are normally distributed, as the significance value (Sig.) is greater than 0.05. Subsequently, a paired samples t-test was conducted, as detailed in Table 5.

Table 5 Paired Sample Statistics

Paired Samples Statistics					
		Mean	**N**	**Std. Deviation**	**Std. Error Mean**
Pair 1	Pretest	55.22	37	10.393	1.709
	Posttest	86.59	37	9.206	1.513

The findings in Table 5 reveal that the average posttest score is significantly higher than the average pretest score. Specifically, the pretest average was 55.22, which increased to 86.59 in the posttest. Additionally, it was noted that the dataset included 37 entries for both the pretest and posttest.

Table 6 Paired Sample Correlations

Paired Samples Correlations				
		N	**Correlation**	**Sig.**
Pair 1	Pretest & Posttest	37	0.108	0.525

Table 6 highlights the correlation value between the pretest and posttest scores, which is 0.108 > 0.05. This result demonstrates a strong and significant relationship between the two average scores.

Table 7 Paired Sample Test

Paired Samples Test									
		Paired Differences					**t**	**df**	**Sig. (2-tailed)**
		Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
					Lower	**Upper**			
Pair 1	Pretest - Posttest	-31.378	13.120	2.157	-35.753	-27.004	-14.548	36	0.000

Finally, the results in Table 7 indicate that the probability or Sig. (2-tailed) value is 0.000, which is less than 0.05. This confirms a significant difference in scores before and after the implementation of RBL-STEM tools, specifically in enhancing students' conjecturing abilities.

4. Conclusion

The research findings on the development of RBL-STEM learning tools to enhance students' conjecturing indicate that these tools meet the criteria for validity, practicality, and effectiveness. The quantitative analysis involved processing pretest and posttest data through normality testing and paired samples t-test. The normality test results confirmed that the pretest and posttest scores followed a normal distribution, as the significance value (Sig.) was greater than 0.05. Additionally, the paired samples t-test revealed a Sig. (2-tailed) value of 0.000, which is less than 0.05. This indicates a significant difference in scores before and after the implementation of the RBL-STEM tools in improving students' conjecturing. The findings demonstrate a substantial increase in students' conjecturing after participating in the learning process. This study serves as a valuable reference for developing RBL-STEM tools aimed at enhancing students' conjecturing.

Compliance with ethical standards

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Disclosure of conflict of interest

As the lead author, I take full responsibility for this research and have collaborated closely with the co-authors as a team. While I aim to maintain objectivity throughout the article preparation, I believe it is important to disclose my professional relationship with my co-authors.

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